AGRICULTURAL LAND USE AND SOIL CARBON IN SLOPING LANDS IN MID-HILL REGION, NEPAL

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Soil carbon (C) is a key part of the global C cycle. Agricultural soils can be both source and sink of the atmospheric carbon dioxide (CO_2). In the Mid-Hill region of Nepal, a lot of the historical soil C has been lost in consequence of the conversion of forests into agricultural lands. However, there is huge potential to increase the soil C sink through appropriate farming practices. The region is characterized by mountainous topography with various microclimates found within a short distance. Thus, also the farming systems differ from each other, which further contributes to the altering soil C accumulation in the region.

This Master's thesis is linked to the project Building Climate Resilience in Farming Systems in Sloping Lands of South Asia, supported by Asia-Pacific Network for Global Change Research (APN). The aim of the study was to find out what is the present soil carbon status in two predominant farming systems in the study site in Kavre, located in the Mid-Hill region, and what are the farming practices contributing to soil C. Soil samples from upland and lowland were taken into the analysis complemented with the interviews of the farmers and the field observations. The effect of the farming practices was investigated in three systems, including the both farming systems, upland solely, and lowland solely. The analysis of variance (ANOVA) was applied for studying the effects of the categorically measured farming practices. The effects of the farming practices classified as continuous variables were measured with the analysis of covariance (ANCOVA).

The results showed that the soil C content was significantly higher in the upland system compared with lowlands. Vegetation cover, agroforestry, and the weed management with weed residues left to the fields were associated with higher soil C stocks. Negative relationship between the chemical fertilizer use and soil C sequestration was found. The use of organic fertilizers, tillage method, tilling intensity, crop residue management and irrigation did not show significant effect on soil C. This study suggests that the aboveground vegetation cover is an integral part of the soil C sequestration in the sloping agricultural lands in the Mid-Hill region of Nepal. Nonetheless, further research with replication and a larger sample size is needed in order to fully investigate the farming practices contributing to the greater soil C contents in the region.

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Tiivistelmä — Referat — Abstract

Maaperän hiili on olennainen osa hiilen globaalia kiertokulkua. Maatalousmaa voi toimia sekä lähteenä että nieluna ilmakehän hiilidioksidin (CO_2) suhteen. Nepalin kukkula-alueella metsien raivaaminen maatalousmaaksi on johtanut maaperän historiallisen hiilivaraston huomattavaan vähenemiseen. Soveltuvien viljelymenetelmien avulla viljelymaan hiilinielua voidaan kuitenkin kasvattaa. Vuoristoisen maastonmuodon vuoksi alueen mikroilmastot poikkeavat toisistaan lyhyenkin etäisyyden sisällä. Näin ollen myös viljelysysteemeissä on eroa, mikä osaltaan vaikuttaa maaperän hiilen vaihteleviin pitoisuuksiin alueella.

Tämä maisterintutkielma on osa projektia Building Climate Resilience in Farming Systems in Sloping Lands of South Asia, joka on toteutettu Asia-Pacific Network for Global Change Research (APN) -verkoston avustuksella. Tutkimuksen tavoitteena oli selvittää maaperän hiilipitoisuuksia kahden vallitsevan viljelysysteemin vaikutusalueella kukkula-alueella sijaitsevassa Kavren kylässä. Lisäksi selvitettiin, mitkä viljelymenetelmät vaikuttavat maaperään sitoutuneen hiilen määrään. Ylänkö- ja alankoalueilta otetut maaperänäytteet sisällytettiin analyysiin, jota täydennettiin viljelijöiden haastatteluilla ja lohkojen havainnoinnilla. Viljelymenetelmien vaikutuksia tutkittiin kolmessa systeemissä, joihin kuuluivat kumpikin viljelysysteemi yhdessä, ylänkösysteemi erikseen ja alankosysteemi erikseen. Kategorisesti mitattujen viljelymenetelmien vaikutusten arvioinnissa hyödynnettiin varianssianalyysia (ANOVA), kun taas jatkuvina muuttujina määritettyjen viljelymenetelmien suhteen käytettiin kovarianssianalyysia (ANCOVA).

Maaperän hiilipitoisuus oli merkitsevästi korkeampi ylänköalueella verrattuna alankoalueeseen. Kasvipeitteisyys, peltometsäviljely, sekä rikkakasvitähteiden jättäminen peltoon olivat yhteydessä suurempiin hiilivarastoihin. Kemiallisten lannoitteiden käytöllä huomattiin olevan negatiivista vaikutusta hiilensidontaan. Eloperäisten lannoitteiden käyttö, maanmuokkausmenetelmä, maanmuokkauksen intensiteetti, viljelykasvien tähteiden käsittely, lohkojen kastelu ja viljelykierto eivät vaikuttaneet merkitsevästi maaperän hiileen. Tämän tutkimuksen perusteella maanpäällinen kasvipeitteisyys on tärkeä tekijä Nepalin kukkula-alueen rinneviljelmien maaperän hiilensidonnassa. Toistettuja tutkimuksia suuremmilla otoksilla kuitenkin tarvitaan selvittämään, mitkä viljelymenetelmät johtavat korkeampiin maaperän hiilipitoisuuksiin alueella.

Avainsanat — Nyckelord — Keywords
Maaperän hiili, kokonaishiili, maankäyttö, viljelymenetelmät, rinneviljelmä, Nepal

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CONTENTS

1 INTRODUCTION

Soil carbon (C) is a key part of the global C cycle. There are five C pools, including oceanic, fossil fuel, pedologic, atmospheric, and biotic pool, of which the pedologic and biotic pools combined constitute the terrestrial pool. The C storage of the terrestrial pool equals four times that of the atmospheric pool (Lal 2010). Only the pedologic pool comprises three times the atmospheric pool, as well as three times the C stored in all the vegetation in the world (Brady and Weil 2002, Lal 2010). The soil C pool has been a source of the carbon dioxide (CO_2) released into the atmosphere since the introduction of settled agriculture (Lal 2010). Recently, the role of agriculture as both source and sink of CO_2 has been widely recognized in accordance with the report of Interngovernmental Panel on Climate Change (IPCC) published in 2014 (Smith et al. 2014). In December 2015, the French government made a suggestion of 0.4% increase in the C concentrations of agricultural soils globally, as a mitigation measure of climate change (Paustian et al. 2016). Thus, much attention has been paid to soils, as they can be turned into C sink through appropriate management (Lal 2010, Paustian et al. 2016, Dignac et al. 2017).

In the context of South Asia, there is lack of information regarding carbon-climate feedback and C sink (Ghimire et al. 2017). Although many studies have focused on the soil C dynamics in the tropical, temperate, and boreal regions, the topic has rarely been studied in the subtropical regions. Particularly, studies in sloping lands would be of great importance, due to the variable conditions along the elevational gradients (Wang et al. 2013). It has been suggested that soil C at high elevations can be even more vulnerable to global warming (Li et al. 2017). In the Mid-Hill region of Nepal, a lot of the historical soil C has been lost in consequence of land use change, primarily through deforestation (Shrestha et al. 2009, Bishwakarma et al. 2014). As being originally covered by dense forest, the region represents a subtropical hotspot of great carbon storage, and thus a potential source and a sink of carbon (Bishwakarma et al. 2014).

This Master's thesis is linked to the project Building Climate Resilience in Farming Systems in Sloping Lands of South Asia, supported by Asia-Pacific Network for Global Change Research (APN) and carried out in Nepal, Bangladesh and Sri Lanka. The aim of the study was to investigate the soil carbon status in 50 farms in the study site in the Mid-Hill region of Nepal. This thesis research was targeted to complement the broader APN project with a specific emphasis on the effects of agricultural land use and farming practices on soil C sequestration.

2 CARBON IN AGRICULTURAL SOILS

2.1 Soil carbon

2.1.1 Soil carbon sequestration

Carbon as an element is the foundation of all life. The carbon cycle involves the soil, the plants, and all the animals, including humans. Plants take carbon as carbon dioxide (CO_2) from the atmosphere. Then, the energy of sunlight is captured in the bonds of organic molecules through the process of photosynthesis. Within the cycle, part of the carbon ends up in soil in the form of the composition of plant residues, or animal wastes and body tissues. Some part of the carbon is returned to the atmosphere as CO_2 through animal exhalation and organic matter metabolization by soil organisms (Brady and Weil 2002).

Soil carbon consists of two components, soil organic carbon (SOC) and soil inorganic carbon (SIC). SOC pool is made up of plant and animal residues, microbial biomass, and microbial by-products, whereas SIC pool comprises the elemental carbon, carbonate minerals and gaseous CO_2 derived from heterotrophic respiration (Lal 2016).
The pedologic carbon pool of 2500 gigatons (Gt) consists of approximately 1550 Gt of SOC and 950 Gt of SIC (Lal 2010). The soil C stocks can be divided into three conceptual C pools based on the degradation rate of soil organic matter (SOM). In the labile pool, SOM turnover occurs from a day to a year. In the intermediate pool, the residence time of SOM ranges between a few years and decades. Finally, SOM turnover in the stable pool occurs within decades to centuries. Most of the SOC is involved in the stable pool (Dignac et al. 2017).

The term soil carbon sequestration refers to the transfer of atmospheric CO_2 into long-lived C pools (Lal 2004, Lal 2007). Soil properties and climate affect the rates of SOC sequestration (Lal 2004). To date, the concept of SOM formation, contributing to the process of C sequestration, has been explained by humification and humic substances. During the past decade, the development of modern analytical tools has led to the re-evaluation of the chemical nature of SOM. The recent findings show that the basis of soil C dynamics lies in microbial growth and activity (Liang et al. 2017), and the humic substances play only a marginal role in organic matter cycling (Schmidt et al. 2011). It has been discovered that the C-containing components of the stable SOM pool are primarily fungal and bacterial necromass. Living microbial biomass covers less than 5% of SOM. Despite being just a small fraction of the C stored in soil, the living biomass is a path through which a considerable amount of C has cycled. The balance between microbial catabolism, which releases CO_2 into the atmosphere, and anabolism, which leads to the senesced biomass and new microbial derived compounds to be accumulated in soils, is an important factor that controls soil C storage formation (Liang et al. 2017).

Soil biotic processes affect SOM dynamics. In addition to the microbial activities, plants alter the soil C stocks through their root systems and litter. Soil macrofauna, of which earthworms, ants and termites often represent a large biomass, have a central influence on SOM dynamics and C stabilization. This group of macrofauna act by mixing soil and fragmenting litter, thus affecting SOM transport. They also form biogenic structures, such as castings, galleries, veneers, and ant or termite hills, contributing to C stabilization. In addition to their intrinsic properties, many groups of soil fauna are able to stimulate microbial activity (Dignac et al. 2017).

The major soil C pool is sensitive to changes in climate or environment. The interactions between SOM and its environment affect the persistence of organic matter (Schmidt et al. 2011). Climate change may alter the soil microbial activity. Extended warming of soil initially increases the biological activity, which further reduces the readily decomposable C. In the long term, the microbial activity tends to decline (Karhu et al. 2014). Ogle (2018) states that the enhanced activity of microbes may weaken the soil carbon sink. According to Bond-Lamberty et al. (2018), accelerated respiration by microbes can release previously stored CO_2 from SOM, and further contribute to global warming. As argued by Wang et al. (2013), CO_2 release from both the labile and recalcitrant C pools may be accelerated with warmer temperatures.

Nitrogen (N) is the main nutrient in organic matter (Bishwakarma et al. 2014). Reduced availability of N to microbes restricts the decomposition of soil organic matter, as the fungal symbionts of plants compete with free-living decomposers. N availability limits both soil C inputs from net primary production and C outputs from microbial decomposition (Averill et al. 2014). Altering soil N contents may contribute to shifts of the microbial community structure, leading to changed decomposition rates (Schmidt et al. 2011). The microbial community exerts a control over the terrestrial C and N cycles. For instance, the study of Averill et al. (2014) shows that the soils dominated by ectomycorrhizal and ericoid mycorrhizal fungi, which produce N-degrading enzymes, hold greater carbon storage than those dominated by arbuscular mycorrhizal fungi.

The role of SOC in soil C sequestration has been studied a lot, but the potential of SIC has received considerably less attention (Lal 2007, Changwen et al. 2012, Shi et al. 2017, Zhao et al. 2018). The major SIC pool is distributed in the soils in arid and semi-arid climates. Since 35% of the Earth's surface is covered by those climates, studying SIC sequestration is essential in order to understand the global terrestrial carbon cycle (Shi et al. 2017). There is also lack of research related to the relationship between SOC and SIC. As studied by Changwen et al. (2012), increases in SIC in arable soils may limit SOC sequestration. Contrary results were obtained by Shi et al. (2017), who reported of the positive relationship between SIC and SOC stocks, and suggested that an increase in SOC may enhance SIC accumulation into croplands.

2.1.2 Carbon management in agriculture

Agriculture and associated land use activities are a source for the most dominant biogenic greenhouse gases: CO_2, methane (CH_4), and nitrous oxide (N_2O) (Paustian et al. 2016). Conversion of natural ecosystems to agroecosystems promotes the soil C loss. The depletion of SOC pool can be as much as 60% in temperate regions and 75% in the tropics (Lal 2004). Together with the land use change and livestock management, soils produce a major share of the agricultural emissions. However, a substantial amount of these emissions can be reduced through improved soil management. Besides increasing SOM content and sequestering C into soil, wise soil management may yield beneficial synergies, such as enhancements in fertility, productivity and soil biodiversity, and increase the adaptation capacity of farming systems to the impacts of climate change (Paustian et al. 2016).

The choice of crop species affects the chemical quality of SOM and the dynamics of SOC. In agricultural systems, crops and varieties that allocate more biomass to the harvested part, which often is the grain, are preferred to increase yields. Thus, less resources are allocated to vegetative parts that contain roots which contribute remarkably to the SOM accumulation (Dignac et al. 2017). A larger and deeper root system is associated with enhanced C sequestration (Acharya et al. 2012, Paustian et al. 2016). The C turnover rate in deeper soil layers is slower, and therefore species with greater root biomass deposit more C into soil (Paustian et al. 2016).

Diverse crop rotations have positive impacts of soil C sequestration, as combinations of different plant groups contribute to the greater belowground biomass production. Soil C inputs can therefore be increased by adopting appropriate crop rotations (Paustian et al. 2016). Inclusion of legumes, for instance, in the crop rotation benefits both the N management and SOC accrual. Legume crops fix atmospheric N into the soil and increase the plant residue input, yield of subsequent crop, and thus total SOC accumulated in the rotation (Ghimire et al. 2017). Intercropping, the practice integrating multiple crop species in a same field, enhances aboveground productivity, promoting also soil C sequestration through yield increases (Cong et al. 2015). The practice of agroforestry, that incorporates trees into the farming system, is also considered as an efficient practice enhancing soil C accumulation (Lal 2004, Feliciano et al. 2018).

Soil and water conservation methods are key systems for agricultural soil C management (Lal 2004). The combination of minimal soil disturbance, crop rotation and crop residue preservation, also known as conservation agriculture, is considered as a potential management system for increasing SOC contents (Fuentes et al. 2012). Continuous vegetation cover is highly linked to the soil C sequestration. Several studies

(Lal 2004, Lal 2007, Ladoni et al. 2016, Paustian et al. 2016) emphasize the importance of cover crops for providing C inputs during fallow periods. When it comes to soil disturbance, in terms of reduced tillage or no-till practises, contrasting results are found. Some authors (Lal 2004, Paustian et al. 2016, Ghimire et al. 2017) report of the positive impacts of minimal tillage on cropland C sequestration, while others (Ogle et al. 2012, Palm et al. 2014) state that the influence can be either positive or negative through possible changes in crop yields. Water conserving methods, such as water harvesting and efficient use of water play a particular role in dryland ecosystems, where the low C stocks can be enhanced through water conservation (Lal 2004).

External sources of organic matter inputs can increase soil C stocks (Lal 2004, Paustian et al. 2016). These sources, whether in the form of compost, biochar, animal manure, or sewage sludge, are also applied for reducing chemical inputs and recycling waste (Paustian et al. 2016, Dignac et al. 2017). Although the practices tend to increase the quantities of added C, their effect on C stabilization is less known. The type of organic matter input plays a role, too. For instance, fresh organic fertilizers may even accelerate SOM mineralization (Dignac et al. 2017), whereas composts and biochar decompose slower than fresh plant residues (Paustian et al. 2016). Additional fertilizer inputs, along with an efficient irrigation, are considered as soil C-increasing practices particularly in water-limited and nutrient-deficient systems (Lal 2004, Paustian et al. 2016).

2.2 Specific features of the Mid-Hill region

2.2.1 Geographical conditions

The Federal Democratic Republic of Nepal is a landlocked country in South Asia positioned between the Republic of India and the People's Republic of China, with the latitudinal range from 26° to 31°N and longitudinal range from 80° to 88°E. Nepal has a land area of 147 181 km^2, of which 70% accounts for mountains of varied altitude. The country is divided into three major ecological zones; the northern High Hills that range in altitude from 2500 up to over 8000 m above sea level, the Mid-Hills covering the elevations from 1300 to 2500 m above sea level, and the southern Terai region, which is an extension of the Indogangetic plain in South Asia and has flat topography in lower elevations (Abbington 1992).

The Mid-Hill region represents the major portion of Nepal, covering 43% of the land area (Abbington 1992). The region includes some of the fertile valleys and major rivers of the country, along with a rugged mountainous landscape (Abbington 1992, Ghimire et al. 2017). Dense population, challenging topography, and limited arable land with poor quality of soils, as well as fragile ecology and active geology, make the agriculture in the region vulnerable (Bajracharya and Shercan 2009).

2.2.2 Soil characteristics

Based on Köppen-Geiger climate classification system, the climate in the Mid-Hills can be classified as temperate with dry winter and hot or warm summer. In a topographically varied country like Nepal, a wide range of climates can be found in the same region (Karki et al. 2016). Due to the differences in microclimate and different parent materials from which the soils are derived, also the soil type can vary considerably within a short distance. Entisoils, inceptisoils, mollisoils and alfisoils are found in the Mid-Hills. According to the indigenous soil classification system, soils are classified by the colour, such as red or black soil, and further defined by soil textures within each colour group (Abbington 1992).

Majority of soils in Nepal are classified as low or medium with regard to organic matter and nitrogen contents. Due to the slower decomposition rates at high elevations, the hills have a slightly higher portion of soils falling into medium or high classes in relation to organic matter status compared to the plains. The soils with medium N status are found as frequently in the hills as in the plains, although the hills have more soils with low N contents (Bajracharya and Shercan 2009). Generally the soils of the hilly regions are acidic, which has been aggravated along the increased use of nitrogenous fertilizers, mainly urea (Raut et al. 2011). In the sloping terrain of the Mid-Hills, soil erosion and decreased soil fertility are among the key concerns in relation to the bio-physical characteristics of the soils (Raut et al. 2011, Das and Bauer 2012, Su et al. 2016).

The Mid-Hill region used to be covered by diverse broadleaf and conifer forests, which represented a great store of carbon. The region has been densely settled and cultivated for several centuries, and much of the forests have been cleared (Bishwakarma et al. 2014). As studied by Shrestha et al. (2009), the removal of trees has led to a dramatic loss in SOC. Since the mature forest soils in the region have a huge capacity to store C, the impact of deforestation is particularly high (Bishwakarma et al. 2014). Road construction, overgrazing and fire are also among the major anthropogenic activities leading to land degradation in the region (Su et al. 2016).

2.2.3 Agricultural land use and management

Bari (upland) and *Khet* (lowland) are the primary systems of agricultural land use, with the former being rainfed and maize *(Zea mays)* and finger millet (*Eleusine coracana)* based, and the latter irrigated paddy rice *(Oryza sativa*) based (Abbington 1992). The Mid-Hill farmers have adapted to the challenging farming conditions and developed management systems in which crop and livestock production is integrated. Thus very small farms can sustain rural communities at subsistence levels (Bishwakarma et al. 2014). Although subsistence farming still remains predominant, an intensification of agriculture has taken place during the past decades (Bajracharya and Shercan 2009, Raut et al. 2011). Especially farmers in peri- and semi-urban areas with sufficient access to urban markets have increased intensified cropping patterns (Bajracharya and Shercan 2009).

The hilly regions of Nepal are prone to flash floods, landslides, and soil erosion in consequence of high rainfall in the monsoon season occurring within a short time span (UNDP 2013). In addition to climatic and geographical factors, some agricultural practices play an important role in erosional processes contributing to C losses in sloping terrace landscapes (Lal 2004, Zhang et al. 2015). In South Asia, crop residues are often removed completely after harvest, owing to their value as fodder and fuel. Thus the SOC from the root zone is depleted, which further decreases the soil productivity (Lal 2004). Tillage is also associated with the loss in SOC from the sloping fields (Shrestha et al. 2009, Zhang et al. 2015). In the Mid-Hills, ox-driven wooden plough is a commonly used tillage tool in addition to hand hoe used in particularly narrow terraces (Das and Bauer 2012).

Compost and farmyard manure have traditionally been the sources of nutrients in the Mid-Hills (Bajracharya and Shercan 2009). As studied by Raut et al. (2011), the intensification of the farming systems began in the mid-1960s along the introduction of chemical fertilizers. The use of fertilizers is highly supported by the government of Nepal since 1973/1974 when the government started to subsidize the price of chemical fertilizers. Aimed to increase production, the use of high-nitrogen and high-phosphorus fertilizers have, on the other hand, resulted in decreasing soil fertility and soil potassium deficits. Urea and diammonium phosphate (DAP) are commonly used by the Mid-hills farmers. The application rates of the fertilizers depend on their availability and the recommendations of fertilizer stores and/or extension workers.

Traditional soil conservation practices, including terrace farming, irrigation canals, and tree and shrub planting on terrace risers, are widely used in the Mid-Hills (Tiwari et al. 2008). The heterogeneous traditional systems include also the elements of crop rotation, grazing of crop residues or zero grazing, and irrigation in the places with a sufficient access to water (Bishwakarma et al. 2014). There have been some initiatives promoting improved conservation technologies, such as terrace improvement, terrace bunds and hedgerow establishment (Tiwari et al. 2008, Das and Bauer 2012). A certain Sloping Agricultural Land Technology (SALT), that is characterized by contour hedgerow intercropping, is a practice used for conserving soil and water, and stabilizing slopes (Lamichhane 2013).

3 RESEARCH OBJECTIVES

The aim of this study was to find out what is the present soil carbon content in sloping agricultural lands in Kavre, located in Mid-Hill region, and what are the farming practices contributing to soil C. The specific objectives of the study were:

1. To compare the total soil C status in two predominant farming systems, upland and lowland.

2. To find out which farming practices result in higher or lower soil C stocks in 1) both farming systems, 2) upland solely, and 3) lowland solely.

The following two-tailed hypotheses were formulated with regards to the farming systems:

H_0= Soil carbon status is not affected by the farming system

H_1= Soil carbon status is affected by the farming system

Similarly, the effect of the farming practices was hypothesized as follows:

H_0= Soil carbon status is not affected by farming practices, when measured either in 1) both farming systems, 2) upland system, or 3) lowland system

H_1= Soil carbon status is affected by farming practices, when measured either in 1) both farming systems, 2) upland system, or 3) lowland system

4 MATERIALS AND METHODS

4.1 Study sites

4.1.1 Description of the location

The field work in Kavre, located 40 kilometres to southeast from the capital Kathmandu (Figure 1), was completed on December 2017. The farms were selected considering their representativeness of the predominant farming systems and suitability for the research project of the APN. Latitude and longitude in the study site ranged from 27°35' to 27°36'N latitude and 85°31' to 85°36'E longitude, with altitudinal range from 922 to 1738 metres above sea level. The locations of the farms (Figure 2) were marked using Garmin GPSmap 62sc tool. In total 50 farmers were interviewed. Majority of the farmers (n= 38) had both upland and lowland in agricultural lands. The studied upland plots located at the elevations between 1395 and 1738 m, and the elevation of lowland plots ranged from 922 to 1341 m. Along the elevation, the major distinction of the upland and lowland was the lands' suitability for paddy cultivation, as paddy rice can be cultivated only in the conditions referred to as lowlands. Specifically, lowland is the land with stagnated water throughout or part of the paddy growing season. The climate of the location is typical for the Mid-Hill region, as being hot and humid during the summer monsoon season, with a long dry season in winter (Table 1).

Figure 1. Location of Kavre shown with a purple marker (Google Maps 2018).

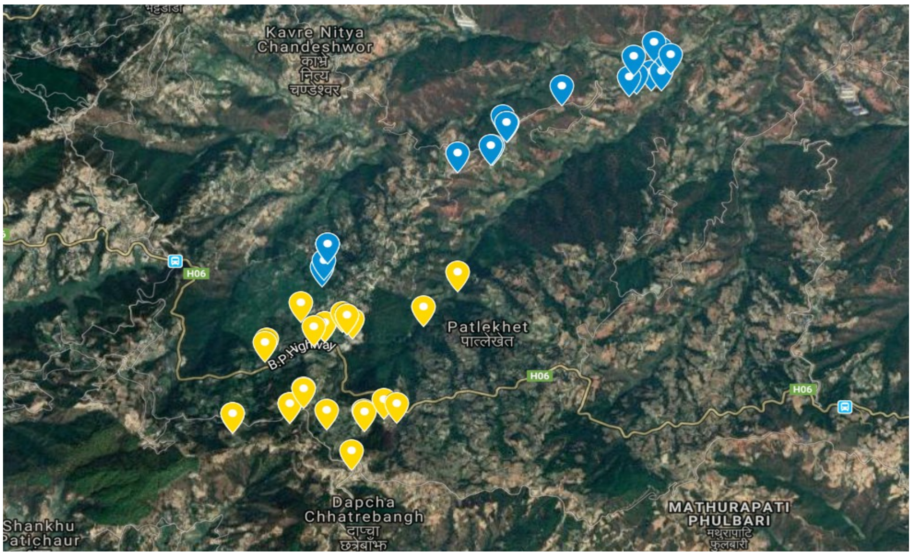

Figure 2. Study sites are located on the northeast facing hill in Kavre. Yellow markers represent the upland plots and blue markers the lowland plots on the valley bottom. All the plots are not visible due to the short distances between the coordinates (Google Maps 2018).

Table 1. Mean annual temperatures (°C) and precipitations (mm) in Dhulikhel, located seven kilometres from the study site in Kavre (Department of Hydrology and Meteorology 2018, ref. Weather Atlas 2018).

Month	Mean high temperature (°C)	Mean low temperature (°C)	Mean precipitation (mm)
January	18	2	11
February	19	4	21
March	24	7	34
April	28	12	67
May	29	16	138
June	29	19	318
July	28	20	517
August	28	20	451
September	28	18	277
October	26	13	74
November	23	7	8
December	19	3	16

4.1.2 Characteristics of the farming system

The farms in the study site are generally diverse and small scale. The average field area of the farms studied is a bit less than 0.7 hectares (ha). Several crop species (Table 2) are included in the crop rotations (Table 3). During the summer season, maize is the major crop in upland. Mustard (*Brassica juncea)*, potato (*Solanum tuberosum)* and wheat *(Triticum aestivum)* are the most important crops grown over winter. Vegetables and legumes are cultivated in upland all year around. Lowland farming is highly based on paddy rice in the summer, complemented by potato in the winter. Fruit trees (Figure 3) are common in homegardens, at the edges of terraces or in the plots as agroforestry species. Many naturally grown trees, such as *Litsea polyantha, Litsea monopetala* and *Ficus sarmentosa* are left on the edges of terraces.

Within this study, the crop rotations were categorized on the basis of crop functional groups due to the small data but various crops existing (Tables 2 & 3). Since the functional properties of flooded paddy cultivated in lowland differ from the properties of other cereals, the rotations including paddy were treated as separate. At the time of sampling, upland plots were mostly under mustard or vegetables. In lowlands, paddy is harvested on November – December, and potato or wheat planted on December – January, so at the time of sampling nothing was growing or the winter crop was at its early stage of development.

Table 2. Crop species included in the rotations. The stages of development, based on the BBCH scale, are listed for the crops grown at the time of sampling.

Crop name	**Crop growth stage (BBCH)**
Brassica juncea	63-69
Brassica oleracea var. botrytis	48
Triticum aestivum	09-10
Citrus spp.	83-89
Spinacia oleracea	44-47
Solanum tuberosum	10-13
Vicia faba	80-83
Oryza sativa	
Zea mays	

Table 3. Crop rotations in the study site. Number of rotations represented in the data (n) is presented in brackets.

Farming system	**Crop rotation (n)**
Upland	Cereal - oilseed crop (8)
	Cereal – potato (8)
	Cereal – legume (2)
	Cereal – mixed vegetables (4)
	Citrus - mixed vegetables – oilseed crop (4)
	Potato - mixed vegetables (1)
	Potato - oilseed crop (1)
Lowland	Paddy – potato (16)
	Paddy - oilseed crop (2)
	Paddy – other cereal (2)
	Paddy - mixed vegetables (1)
	Legume - oilseed crop (1)

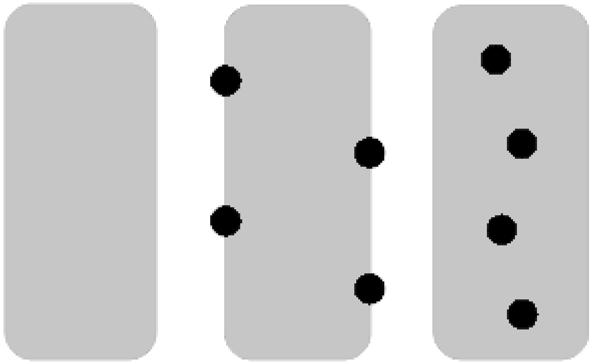

Figure 3. Different tree arrangements in relation to the terraces, including 'no trees', 'trees at the edge', and 'agroforestry', respectively. The figure is not drawn to scale.

Small-scale animal husbandry is practiced by all of the farmers. Typically, each household have 1 to 2 cows and buffalos, and a small herd of goats or chickens. Cut and fed is the predominant method of feeding of the cows and buffalos, as grazing is not possible due to the slope and the field area concentrated on narrow terraces. The feed is taken from the homegardens and the plots nearby the house, since the animal shelters tend to be positioned near the houses. Chickens, and in some cases goats, are often free grazed or supplied with both the cut feed and grazing opportunities.

Farmyard manure (FYM) based compost have been applied by 88% of the farmers, and it is a widely used fertilizer for annual and sometimes for perennial crops. Manure is often stored in heaps near the upland plots. Chemical fertilizer use is also common, since 90% of the farmers have used urea and 68% diammonium phosphate (DAP) for annual crops. Perennial crops are often managed with no fertilization. Majority of the plots in upland are rainfed, with some exceptions of water harvesting being practised. Lowland plots are both rainfed and irrigated, since there is a water supply from a stream. Most of the farmers till the soil with the motor-driven minitiller. The other methods used include hand tillage, ox-driven plough and tillage by powertiller. The predominant tilling frequency is twice per year. Organic matter from weed and crop residues is either left to the fields or fed to animals. Some soil conservation methods, such as cover cropping, mulching, lock and spill drains, stone bunds, and SALT system are used by minority of the farmers.

4.2 Interviews

Quantitative data from soil sampling was complemented by interviewing the farmers. Structured interviews were combined to investigate the various aspects of the research. Within the guidelines of the APN project, an exhaustive interview concerning farming, food consumption and livelihood was implemented. That questionnaire did not involve the variables included in the statistical analysis for this Master's thesis, but was used for gathering overall knowledge of the farms. Parts of the questionnaire answers were used as research material, specifically for the study site characterization in the previous chapter.

A plot-specific questionnaire with a special emphasis on the farming practices contributing to soil C was made to support the soil sampling data. The factors studied were the use of fertilizers, irrigation, tilling intensity, tilling method, crop rotation, weed management and crop residue management. Most of the questions were open and put into categories afterwards, as parallel answers existed in many cases. In the case of fertilizer use, the application rates were asked by kilograms (kg) used per plot during the previous growing season. The quantities were transferred to equal kg per ropani, which is a commonly used Nepalese unit for land area. One ropani equals to 0.05 ha. The farmers measure the plot sizes per ropanis, so the conversion from kg/ropani to kg/ha was done afterwards.

The interviews of the farmers were completed via local interpreter. The interviews were held in Nepali language, and the answers were written down on the questionnaire form in English by the interpreter. Each interview session was held approximately in one hour. At the time of interviews, visits were made to the plots where the samples were taken. The inclination of the plots was estimated using a digital clinometer application. The arrangement of planted or naturally grown trees in relation to the plots was estimated based on observation.

4.3 Soil sampling

From each farm, a soil sample was taken from the plot which the farmer relied most on within the certain farming system. The farmers interviewed in upland (n= 28) were asked to choose their most important upland plot, and within the same line of reasoning the farmers met in lowland (n= 22) were asked to show their most important lowland plot. Six soil cores were sampled per each plot. Sampling locations were decided to be divided evenly on the field, depending on the shape of the plot. In round or square shaped plots, the locations were arranged in two rows (Figure 4). In narrow terraces, the longitudinal arrangement was implemented (Figure 5). In both farming systems, a terrace was considered as a plot.

Soil samples were taken using a standard soil core brought from the University of Helsinki. The sampling depth was 18 centimetres (cm) in upland and 24 cm in lowland. The reason for the diverging sampling depth was the difference in soil moisture, the soil being significantly drier and harder to sample in uplands. This was not possible to fix anymore at the time of field work, so the unstandard sampling procedure is taken into account in the evaluation of the results. There was no difference in the depth of tilling layer, so the difference in the sampling conditions was simply the result of irrigation in lowland and lack of it in upland. The thin topsoil of approximately 2-3 cm was removed and not included in the sample. The six soil cores taken from each plot were mixed in a bucket. The sample material of 200 grams (g) each, based on observation, was moved to a box. Sub-samples of circa 2 g each were taken and air-dried after thorough mixing using a spoon. Due to the higher moisture content, the samples taken from lowland needed around 48 hours of drying, whereas the upland samples dried within 24 hours. Air drying temperature was around 15 °C.

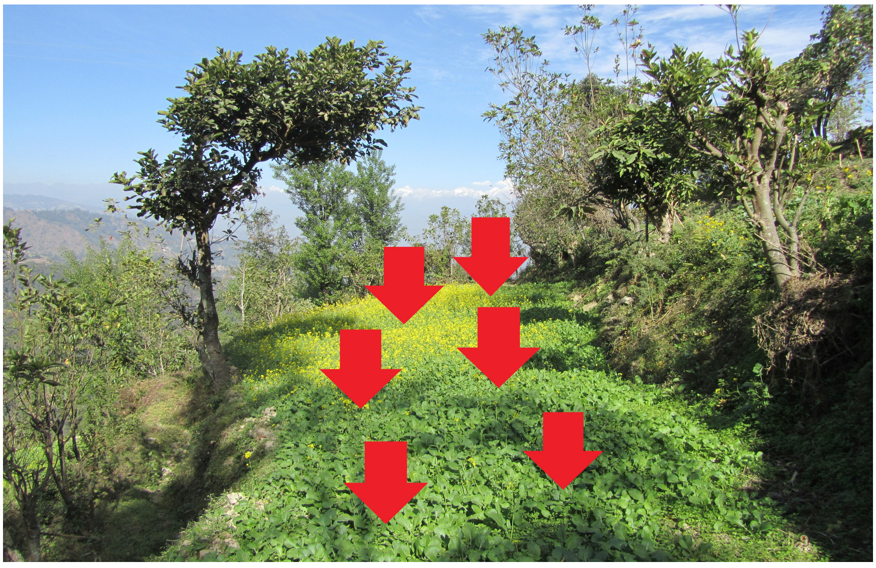

Figure 4. Sampling spots in a square shaped plot.

Figure 5. Sampling spots in a narrow terrace.

4.4 Standard soil characterization

Standard characterization of the soil was conducted in the soil laboratory of the Himalayan Institute of Agricultural Science and Technology, which operates under Purbanchal University in Nepal. After preparing the sub-samples from the full samples of 200 g each, the boxes with the remaining sample material were sent to Purbanchal University for the soil analysis. There, the analysis of potassium (K) was done by ammonium acetate method, phosphorus (P) by Olsen method, nitrogen (N) by Kjeldahl method, and organic matter by Walkley-Black method (Khem Raj Dahal, Tribhuvan University, personal notice 30.1.2019). The values of the soil properties were tested against the C results obtained, using the soil properties other than C only as independent variables. There was an uncertainty in the laboratory analysis of organic matter content by Walkley-Black method, resulting in the need of reprocess.

4.5 Laboratory analysis for soil C and N

Air-dried soil sub-samples were brought to the University of Helsinki Viikki laboratory facilities for an analysis of total carbon by Vario Max CN analyser (Elementar, Hanau, Germany) during January and February 2018. After the analysis, the moisture content was measured by drying the samples in an oven at 105°C for 16 hours.

The final soil C results were calculated as follows:

$$C_{tot} = \frac{100}{100 - M_n} C_n \tag{1}$$

where

C_{tot} = final carbon content (%)

M_n = moisture content (%)

C_n = carbon content before oven drying (%)

Soil nitrogen contents were measured within the same procedure. The values for N contents were tested against the values of C, but effects of the farming system and farming practices on the soil N status were not examined for this thesis research.

4.6 Statistical analysis

Data were organized with OpenOffice (version 4.1.5, Apache Software Foundation, Forest Hill, MD, USA). Statistical analysis was completed using SPSS (version 25.0, SPSS Inc., Chicago, IL, USA). Normality of the data was confirmed with Kolmogorov-Smirnov test of the equality of distributions. After ensuring the suitability of the projected model, the general linear model was applied to analysis of variance (ANOVA) with categorical variables and analysis of covariance (ANCOVA) with both categorical and continuous variables. The majority of the analyses were run through ANOVA, since most of the variables were defined as categorical. In the case of the fertilizer use, the analysis involved both the continuous variable measuring the quantities of certain fertilizer used and the categorical variable measuring whether the fertilizer has been used at all or not. Organic fertilizers were divided into the sub-groups of different types of manure, but due to the inadequate sampling size the sub-groups were excluded from the analysis.

The statistical analysis was done in four steps. Firstly, exploratory analysis was conducted for summarizing the main characteristics of the two farming systems and the farming practices in both farming systems, upland and lowland. Secondly, 2-way ANOVA and ANCOVA were used for the main effects of each farming practice, when the farming system was treated as a fixed factor. In cases of tillage method and tree arrangement, there was a small difference between the existing categories in the two farming systems. Thus, the categories existing only in either upland or lowland were excluded from 2-way ANOVA. The effect of crop rotation was analyzed only in upland and lowland solely, since the rotations were not comparable. Thirdly, one-way ANOVA and ANCOVA tables were created for analysing the main effects of the farming practices within upland and lowland systems separately. The fourth step of the analysis was to perform 2-way ANOVA for the interaction effects between the different farming practices in both systems, upland system, and lowland system.

The effect of each categorical variable, the effect of farming system and the interaction of the variable and farming system were calculated by using the following formula:

$$Y = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk} \tag{2}$$

where

μ = grand mean

α_i = main effect of the variable

β_j = effect of the farming system

γ_{ij} = interaction effect of the farming system and the variable

ε_{ijk} = random errors

The effect of the continuous variables were calculated as follows:

$$Y = \mu + \tau_j + \beta\left(x_{ij} + \bar{x}\right) + \varepsilon_{ij} \tag{3}$$

where

μ = grand mean

τ_j = the treatment effect of the farming system

β = slope of the line

x_{ij} = observation of the covariate

$\bar{x}$ = overall mean of x

ε_{ij} = random errors

Finally, the following formula was applied for the main effect of each variable in either upland or lowland system:

$$Y = \mu + \tau_j + \varepsilon_{ij} \tag{4}$$

where

μ = grand mean

τ_j = the treatment effect of the variable

ε_{ij} = random errors

The formula 2 was also applied for the interaction effects between different farming practices, by changing the variable 'farming system' to the other variable to be tested.

All the evidence was tested against the null hypothesis H_0. The interpretation of the results was based on the significance level of the probability of Type I error (P value) for the F-test. P values < 0.05, < 0.01, and < 0.001 were considered as significant, very significant and highly significant, respectively. A significance level of $P < 0.1$ was interpreted as indicating suggestive significance.

5 RESULTS

5.1 Farming system

The farming system appeared to be statistically highly significant (*P*=0.000) in relation to soil C. The average C content in the upland plots (Mean=1.80%) was remarkably higher than in the lowland plots (Mean=1.18%) (Figure 6). The mean C content of all the plots was 1.53%.

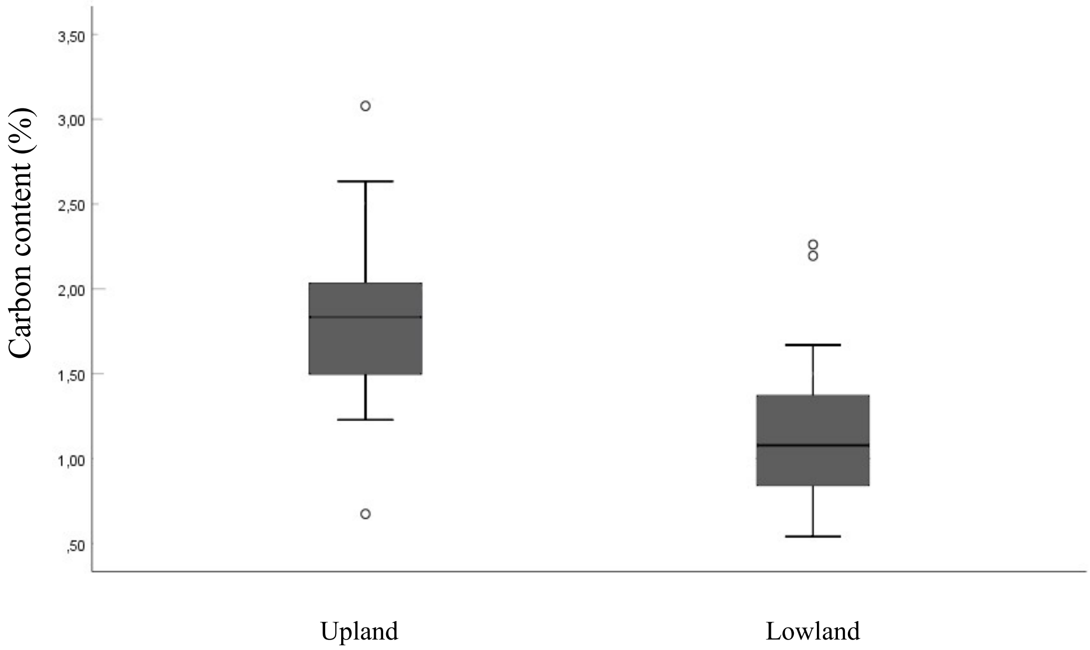

Figure 6. Mean carbon contents (C%) in agricultural soil in the upland and lowland systems in the Mid-Hill region of Nepal. The error bars show the standard errors of means (±SEM).

5.2 Fertilizer use

The use of compost, measured both continuously and categorically, had no significant impacts on soil C in any systems (Tables 4 & 5). The quantities of the chemical fertilizers used did not affect soil C either (Table 5). In the upland plots, soil C content was significantly lower in the plots were urea (*P*=0.033) or DAP (*P*=0.013) had been applied (Tables 4 & 6). There was only one interaction effect found between the

Table 4. Results of ANOVA (F-tests) for the main effects of the categorically measured farming practices on soil C% in both farming systems, upland, and lowland in the Mid-Hill region of Nepal. The significant *P*-values (<0.05) are shown as bolded.

	All plots			Upland plots			Lowland plots		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Compost	1	0.140	n.s.	1	3.547	0.071	1	1.426	n.s.
Urea	1	0.125	n.s.	1	5.048	**0.033***	1	0.569	n.s.
DAP	1	0.192	n.s.	1	7.180	**0.013***	1	0.651	n.s.
Crop rotation	-	-	-	6	1.278	n.s.	4	0.276	n.s.
Vegetation cover	1	9.198	**0.004****	1	6.522	**0.017***	1	3.189	0.089
Tilling method	1	0.002	n.s.	2	0.988	n.s.	2	0.966	n.s.
Tillage intensity	2	1.083	n.s.	2	2.954	0.071	2	0.330	n.s.
Tree arrangement	1	2.968	0.092	2	2.166	n.s.	1	5.402	**0.031***
Weed management	1	0.389	n.s.	1	6.938	**0.017***	1	2.257	n.s.
Crop residue management	1	0.409	n.s.	1	2.310	n.s.	1	0.229	n.s.
Irrigation	1	0.038	n.s.	1	0.286	n.s.	1	0.000	n.s.

*, **, *** $P < 0.05, 0.01, 0.001$, respectively. $P > 0.1$ = n.s. (not significant)

Table 5. Results of ANCOVA (F-tests) for the main effects of the fertilizer use, as measured by kg/ha, on soil C% in both farming systems, upland, and lowland in the Mid-Hill region of Nepal.

	All plots			Upland plots			Lowland plots		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Compost, kg/ha	1	0.088	n.s.	1	0.049	n.s.	1	0.072	n.s.
Urea, kg/ha	1	0.024	n.s.	1	0.035	n.s.	1	0.005	n.s.
DAP, kg/ha	1	0.124	n.s.	1	0.143	n.s.	1	0.061	n.s.

$P > 0.1$ = n.s. (not significant)

fertilizer use and the other farming practices. A case showing a very significant interaction effect was found between the DAP use and the crop rotation. In the upland system, significantly lower C contents (P=0.005) associated with DAP use were measured in the plots under cereal-potato rotation (Figure 7).

Table 6. Mean soil C contents (%) under certain farming practices in both farming systems, upland and lowland in the Mid-Hill region of Nepal. The table includes the farming practices as categorical variables, numbers of observations (n) and standard errors of means (SEM).

		All plots			**Upland plots**			**Lowland plots**		
		Mean	n	SEM	Mean	n	SEM	Mean	n	SEM
Compost	added	1.53	47	0.078	1.77	27	0.087	1.21	20	0.102
	not added	1.42	3	0.605	2.63	1	-	0.82	2	0.024
Urea	added	1.48	45	0.078	1.739	24	0.092	1.19	21	0.099
	not added	1.98	5	0.312	2.26	4	0.168	0.84	1	-
DAP	added	1.36	34	0.082	1.59	14	0.110	1.21	20	0.104
	not added	1.88	16	0.139	2.02	14	0.118	0.93	2	0.088
Vegetation cover	yes	1.62	41	0.084	1.90	23	0.087	1.25	18	0.109
	no	1.12	9	0.148	1.36	5	0.214	0.83	4	0.053
Tilling method	Hand tillage	2.10	5	0.184	2.10	5	0.184	-	-	-
	Minitiller	1.45	29	0.101	1.74	12	0.148	1.24	17	0.115
	Local plough	1.68	10	0.109	1.79	8	0.097	1.21	2	0.066
	Power tiller	0.94	2	0.106	-	-	-	0.94	2	0.106
Tillage intensity	Once per year	1.87	2	0.761	2.63	1	-	1.11	1	-
	Twice per year	1.56	41	0.080	1.75	26	0.086	1.23	15	0.122
	Three times per year	1.25	7	0.246	2.41	1	-	1.05	6	0.178
Tree arrangement	No trees	1.17	20	0.082	1.65	4	0.150	1.05	16	0.070
	Trees at the edge	1.69	26	0.104	1.75	20	0.110	1.51	6	0.269
	Agroforestry	2.23	4	0.147	2.23	4	0.147	-	-	-
Weeds	Left to field	1.63	22	0.086	2.22	4	0.150	1.08	15	0.113
	Removed	1.32	19	0.144	1.72	16	0.882	1.40	6	0.190
Crop residues	Left to field	1.49	7	0.239	1.48	4	0.280	1.29	3	0.483
	Removed	1.55	43	0.083	1.86	24	0.091	1.16	19	0.090
Irrigation	Rainfed	1.81	11	0.148	1.88	10	0.146	1.15	1	-
	Rainfed and irrigated	1.35	26	0.093	1.78	8	0.096	1.16	18	0.099

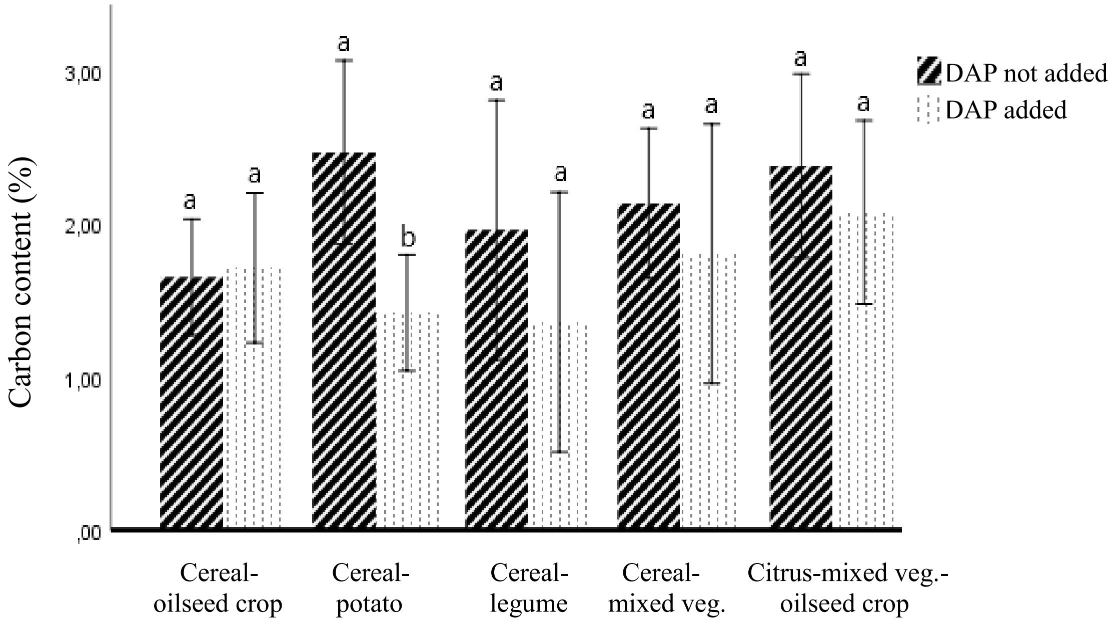

Figure 7. Effect of diammonium phosphate (DAP) use on soil C% in upland crop rotations in the Mid-Hill region of Nepal. Only the rotations where both treatments (added / not added) existed are visible in the picture. The error bars show the standard errors of means (±SEM). Significant ($P<0.05$) interactions are indicated by different letters above the histograms.

5.3 Irrigation

Irrigation had no significant ($P>0.05$) impact on soil C. The rainfed upland plots had higher mean soil C than the plots with both rainfed and irrigated water sources (Table 6). There were no interaction effects found between irrigation and any other farming practices.

5.4 Tillage

The frequency of tillage did not show significant impact ($P>0.05$) in any systems. There was an indication of suggestive significance ($P=0.071$, Table 4) in upland related to tilling intensity and soil C, as the highest C contents were measured in the plots which had been tilled only once per year (Table 6). The tillage method had no significant impact on soil C ($P>0.05$). The plots tilled by hand, which was practised only in upland, had the highest soil C contents (Table 6). The tilling intensity and tillage method did not show significant interaction effects between any other variables.

5.5 Crop rotation

The highest mean C contents in upland were measured under citrus - mixed vegetables - oilseed crop rotation, followed by cereal - mixed vegetables rotation (Table 7). In lowland, there was less variation in the rotations, and the highest C content was measured under paddy - mixed vegetables rotation which existed only once (Table 7). The crop rotation did not affect significantly (P>0.05) on soil C. When measured in terms of vegetation cover, the crop rotation had a very significant impact on soil C in both systems (P=0.004), a significant impact in upland (P=0.017), and a suggestive impact (P=0.089) in lowland (Table 4). The plots covered with vegetation had higher soil C contents than the plots that were barren at the time of sampling (Table 6).

Table 7. Mean soil C contents (%) under different crop rotations in the upland and lowland farming systems in the Mid-Hill region of Nepal. The table includes the number of rotations represented in the data (n) and the standard errors of means (SEM).

Farming system	Crop rotation	Mean	n	SEM
Upland	Cereal - oilseed crop	1.68	8	0.086
	Cereal – potato	1.68	8	0.243
	Cereal – legume	1.66	2	0.301
	Cereal – mixed vegetables	2.05	4	0.137
	Citrus - mixed vegetables – oilseed crop	2.23	4	0.147
	Potato - mixed vegetables	1.23	1	-
	Potato - oilseed crop	1.89	1	-
Lowland	Paddy – potato	1.15	16	0.127
	Paddy - oilseed crop	1.16	2	0.118
	Paddy – other cereal	1.19	2	0.176
	Paddy - mixed vegetables	1.67	1	-
	Legume - oilseed crop	1.15	1	-

5.6 Weed and crop residue management

The practice of leaving weed residues to the plot increased the soil C significantly (P=0.017) in the upland system. Weed treatment had no significant impacts (P>0.05) when measured in both systems or in lowland. There were no interaction effects found between the weed treatment and the other farming practices. In case of crop residues, the treatment did not affect soil C contents (P>0.05) in any systems. Significant impacts were not found either between the crop residue treatment and any other farming practice.

5.7 Tree arrangement

Integration of trees into the plots was positively related to increases in the soil C content. In upland, the highest soil C contents were measured in the plots where trees were integrated as an agroforestry practice, followed by the plots with trees at the edge (Table 6, Figure 8). Statistical significance (P=0.031) was found in the lowland system, where only two categories of tree arrangement, 'no trees' and 'trees at the edge', existed (Table 6, Figure 8). A trend towards suggestive significance (P=0.092) was discovered in the both farming systems, when the two categories existing in both of the systems were analyzed.

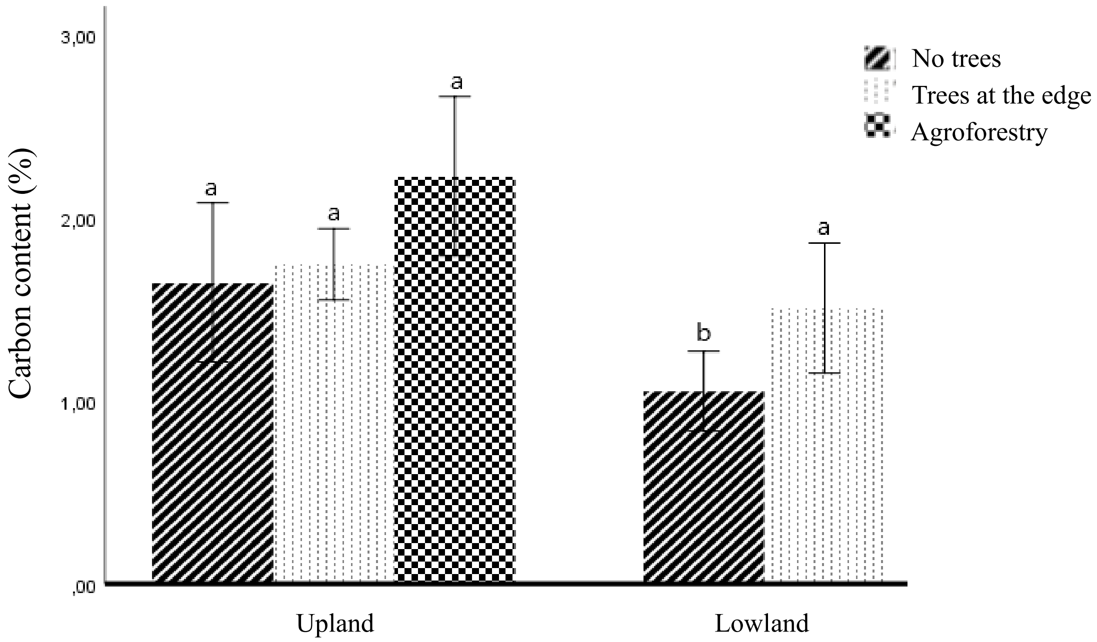

Figure 8. Effects of tree arrangement on soil C content (C%) in agricultural lands in upland and lowland systems in the Mid-Hill region of Nepal. The error bars show the standard errors of means (±SEM). Significant (P<0.05) differences are indicated by different letters above the histograms.

5.8 Slope

Overall elevation had a highly significant (*P*=0.000) impact on soil C, as the C content increased along the increasing elevation (Figure 9). Inclination of the plots had a very significant (*P*=0.006) impact in upland. Growing inclination was associated with the decreasing soil C content (Figure 9). In lowland, there was practically no difference in the inclination of the plots.

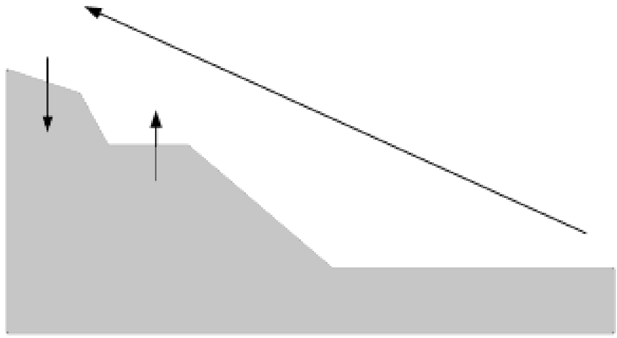

Figure 9. Soil C contents as affected by the elevational gradient and the altering plot inclination in agricultural lands in the Mid-Hill region of Nepal, with the altitudinal range between 922 and 1738 m above sea level. The arrows show the increasing or decreasing C content. The figure is not drawn to scale.

5.9 Soil properties

Standard characterization of the soil showed that the silty loam was the major soil type, followed by clay loam and silty/sandy clay loam. The range of pH was between 4.8 and 7.4. Slightly higher pH and lower potassium (K) contents were found in lowland soils. Phosphorus (P), nitrogen (N) and organic matter (OM) contents remained similar in both of the systems (Table 8, Appendix 1, Tables 10 & 11).

Soil properties, including pH, and the contents of K, P and OM, did not correlate with the soil C contents in any systems (Table 9). The soil N contents ran parallel with the C contents in both systems (*P*=0.000), upland (*P*=0.007), and lowland (*P*=0.000), when measured by Vario Max. The analysis of N completed through Kjeldahl method did not give any responses to soil C (*P*>0.05). Soil type was not associated with the C contents in any of the systems (*P*>0.05).

Table 8. Soil properties in agricultural land in upland and lowland system in the Mid-Hill region of Nepal. Number of plots (n) for each soil type is presented in brackets. Data are from the analysis completed in the Himalayan Institute of Agricultural Science and Technology in Purbanchal University in Nepal.

	Upland	**Lowland**
Soil property	**Mean**	**Mean**
pH	5.87	6.27
K (kg/ha)	540.80	329.89
P (kg/ha)	55.69	54.68
N (%)	0.21	0.21
OM (%)	4.10	4.13
Soil type (n)	Silty loam (9)	Silty loam (7)
	Clay loam (6)	Clay loam (4)
	Silty clay loam (6)	Sandy clay loam (3)
	Silty clay (3)	Silty clay loam (3)
	Sandy clay loam (2)	Loamy sand (1)
	Clay (1)	Sandy (1)
	Sandy clay (1)	Sandy clay (1)
		Sandy loam (1)

Table 9. Results of ANCOVA (F-tests) for the main effects of the soil properties on soil C% in both farming systems, upland, and lowland in the Mid-Hill region of Nepal. The significant *P*-values (<0.05) are shown as bolded.

	All plots			**Upland plots**			**Lowland plots**		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
pH	1	0.022	n.s.	1	0.308	n.s.	1	1.665	n.s.
K, kg/ha	1	0.624	n.s.	1	1.1618	n.s.	1	3.129	n.s.
P, kg/ha	1	0.034	n.s.	1	1.002	n.s.	1	1.123	n.s.
N (%) (Kjeldahl method)	1	2.121	n.s.	1	2.237	n.s.	1	0.066	n.s.
N (%) (Vario Max)	1	27.419	**0.000*****	1	17.115	**0.007****	1	17.909	**0.000*****
OM (%)	1	0.852	n.s.	1	1.082	n.s.	1	0.816	n.s.

*, **, *** $P < 0.05, 0.01, 0.001$, respectively. $P > 0.1$ = n.s. (not significant)

6 DISCUSSION

6.1 Study sites

The interviews were of vital importance in this thesis research, since the information about the study sites was gathered by interviewing each farmer. Due to the language barrier, me as an independent researcher had no full control over the interviews. There is always a risk that some question is understood differently by the researcher, the interpreter or the interviewee. As the answers were written down in English by the interpreter, the possibility to check misunderstandings was weakened. Some answers were missed, which naturally affects the reliability of the data within the small sample size.

The soil C contents of the plots were exceptionally high for the typical contents in the agricultural lands of the Mid-Hills (Khem Raj Dahal, Tribhuvan University, personal notice 30.1.2019). The experimental design may provide a partial explanation, since the farmers were asked to show their most important field. Thus, it can be assumed that the plots sampled were treated with the best management practices available. Sampling from other plots of the same farmer might have given distinctive results of the general soil C status in the region. Moreover, the study site was a northeast facing slope, which can contribute to relatively high average C stocks. In the Mid-Hill region, this was studied by Begum et al. (2013), who observed notably higher soil C contents on a north facing slope compared to a south facing slope.

Topographic variability and altering microclimate along the elevational gradients can cause one source of variation. Shrestha et al. (2004) argued that the spatial variability can cause variation in SOC in a mountainous study site. In this study, some attention should be paid to the consideration of a plot. A plot was often one terrace of a sloping field. The slope position of the plots in relation to the field was not investigated, so there is no possibility to analyze the C contents along toposequences. As studied by Su et al. (2016), soil erosion rate was smaller and C content was higher in lower slopes of the fields located in the Mid-Hills. In the sloping agricultural lands of China, the study of Zhang et al. (2015) revealed that the highest amount of SOC was accumulated into the toe portion of the slope. Since the farmers decided the plot to be sampled, it was not possible to make any standardization of the positions or conditions of the plots. However, the experiment confined to the most important plots may have reduced other sources of variation, caused by too variable management practices, for instance.

6.2 Farming systems

In case of the farming systems, the result of considerably higher soil C contents in upland was clear enough for accepting the alternative hypothesis (H_1), which assumed that the farming system affects the soil C sequestration. Sufficient evidence was found in favour of the upland plots storing significantly higher amounts of C. Similar results from the Asian sloping lands were obtained by Wang et al. (2016a), who found that total organic C increased along the elevation. In the Mid-Hill region, higher SOM contents are often found in upper hill slopes compared to valley bottoms (Bajracharya and Shercan 2009). Particularly, Wang et al. (2016a) deduced that the microbial activity can be restricted by lower temperatures at high elevations, which further explains the differences in SOC accumulation. Altered microbial community structure in colder temperatures might play a role, too (Wang et al. 2013).

Surprisingly, unexpected results were obtained since the SOM contents did not run parallel with the C contents. Although the higher C stocks were measured in upland, there was no difference in SOM contents between the farming systems (Appendix 1, Tables 10 & 11). One explanation can be deduced from variability in the composition of SOM under the different microclimates in upland and lowland. Simply, more oxidized organic matters are found in warmer climates (Bianchi et al. 2008). Thus, the proportion of oxygen in SOM may be greater in lowland at the expense of C. According to the prevailing assumption, SOM contains 58% carbon. As argued by Pribyl (2010), the oxidation rate of SOM is highly variable, and therefore applying an average value to any individual soil may produce a large amount of error.

The methods used to measure SOM and C contents can be a source of variation. For both the SOM measurement by Walkley-Black, and the C measurement by Vario Max, the relative deviances were within the accepted level. Thus it is possible that the used method is not the only factor explaining the contrasting results of SOM and C contents, although it is very likely that the effect of the measurement is of great importance. The measurement completed by Walkley-Black does not contain any forms of elemental C (Pribyl 2010). Vario Max measures the total C, including both SOC and SIC. Further, the different farming practices typical to upland and lowland systems are worth to take into account. The study of Shi et al. (2017), showed that low SIC contents were associated with the low soil pools of Ca^{2+} and Mg^{2}+ cations. As reported by Lucas et al. (2011) and Perakis et al. (2013), N additions contribute to the declining trend of soil Ca^{2+} and Mg^{2+} stocks. Lal (2007) argues that the use of certain management practices, including application of compost, can enhance SIC sequestration. Since the use of nitrogenous fertilizers is predominant in lowland, while upland plots rely more on organic fertilizers, the difference in the fertilizer use can be considered as a noteworthy factor. However, the contents of carbonaceous minerals, that would have given a more plausible explanation for the possible difference caused by SIC, were not measured neither by Walkley-Black nor Vario Max.

The sampling procedure can produce a source of variation. The shallower sampling depth in upland (0-18 cm) than in lowland (0-24 cm) is worth considering. The study of Shrestha et al. (2004) found out that particularly the lowland soils held significantly higher SOC stocks in the 0-10 cm depth compared to lower layers. Similarly, Bianchi et al. (2008) showed that the SOM in the subsoil contained less C but more O than the SOM in the upper soil layer. However, the difference was remarkable only after 40 cm depth, so this may provide only a minor explanation. When it comes to SIC dynamics in relation to the soil layers, opposite results have been reported. Changwen et al. (2012) observed higher SIC contents near the soil surface. In contrast, the study of Shi et al. (2017) showed that SIC contents increased with the sampling depth.

Some attention should be paid to the difference in the soil moisture between the samples taken in upland and lowland, since the air-drying time of the lowland samples was much longer. According to Sun et al. (2015), air-drying of soil samples is associated with the enhanced mineralization of organic matter. Further, Makarov et al. (2017) suggested that the effect of drying on the C contents of soil samples is even more notable for wet soils than those drier under natural conditions. Thus, it is possible that the higher moisture contents and longer drying times of lowland samples contributed to the lower C contents measured in lowland.

The physical properties of the plots can affect the soil C accumulation under the two farming systems. According to Acharya et al. (2008), the terraces that have developed the S-shaped profile are more prone to rilling and water erosion than the bench-terraced plots. As many of the studied lowland plots were considered as S-shaped and upland plots as bench-terraced, the shape of the plots is a factor worth considering. With a special regard to upland, soil C status was also related to the plot inclination. Similar findings were reported by Su et al. (2016), who observed decreasing C contents with the increasing inclination.

6.3 Farming practices

Since the effect of the farming practices on soil C varied by practice, there was also variation in the application of the null hypothesis (H_0) in support of this research. When evaluating the importance of the farming practices at the general level, the alternative hypothesis (H_1) is supported in cases of chemical fertilizer use, vegetation cover, tree arrangement and weed management. In contrast, the results obtained from the organic fertilizer use, tilling method, tillage intensity, crop residue management, irrigation and crop rotation did not provide sufficient evidence to reject H_0. Most of all, the highest support for accepting H_1 was gained in the case of vegetation cover.

The abundance of aboveground vegetation was highly linked with the C sequestration. The effect of vegetation cover as measured in both farming systems can be partly explained by the difference between the upland and lowland plots, since the upland plots were more frequently under standing vegetation at the time of sampling. However, the significant difference was observed also when measured in upland solely. As studied by Ruiz-Colmenero et al. (2013) and Wang et al. (2016b), aboveground vegetation enhanced soil C accumulation. According to Ladoni et al. (2016), the use of cover crops had a positive impact on C sequestration in sloping agricultural lands. Further, they noted that the effect of cover crops was higher on topographical positions of slopes and summits, compared to depressions. This provides an interesting viewpoint for the inspection of the results gained in the upland system.

The type of vegetation was noted to have an influence in terms of tree arrangement. Growing trees in the immediate vicinity of the plots showed up as a promising practice to enhance soil C sequestration. Parallel results were discovered in the Mid-Hill region by Schwab et al. (2015), and in the sloping lands of eastern India by Lenka et al. (2012). Integration of trees into the farming system seemed to have more impact in lowland, which may be explained by the different microclimates and the higher moisture contents in valley bottoms (Pandit et al. 2012). The different crop species included in the rotations may also be worth considering. As studied per SOM contents, higher stocks have been measured under maize cropping system compared to the systems based on paddy and wheat (Bajracharya and Shercan 2009).

Some uncertainties were explored in the analysis of the fertilizer use. It can be questioned, whether the chemical fertilizer use actually decreases soil C or is the difference rather a consequence of the use of organic fertilizers or the other carbon management practices, such as agroforestry, on the plots where chemical fertilizers had not been applied. In Nepal, the quantities of fertilizers are not measured so strictly, so the non-significant values obtained from the analysis by kg/ha were predictable. Although the compost use did not give any significant results in this study, many other authors (Shrestha et al. 2004, Shrestha et al. 2009, Bajracharya and Shercan 2009) have reported of the soil C increases associated with the organic fertilizer use in the Mid-Hills. Particularly, the higher C contents in uplands are explained by the organic fertilizer use. The farmers tend to live on the upper hill slopes, so the compost is easier to carry to upland fields.

A larger sample size and replicated experiments would be needed to sum up which farming practices contribute to the soil C build-up in the Mid-Hill region. In this study, the farming practices were not investigated in depth, and some of the relatively common practices were not used in the farms studied. As an example, not only the use but the management of farmyard manure (FYM) affects the soil C sequestration. The traditional way of storing FYM in the open with a haphazard bedding leads to loss of C before it is applied into the soil. A more improved bedding, along with the protection from direct rainfall and direct sunlight are needed for preventing C losses and improving soil quality (Chapagain and Gurung 2010, Bishwakarma et al. 2014, Shrestha 2015). Limited number of animals and lack of grazing lands have made it challenging to have enough manure for fertilization, thus increasing the efficiency of the FYM management is of a great importance (Bishwakarma et al. 2014). As an another example, this study did not find any significant impacts of the intensity and method of tillage on soil C. Worth to note, reduced or no till management were not practiced in the study site, though those have been considered as beneficial strategies to enhance C stocks in the agroecosystems of South Asia (Ghimire et al. 2017).

7 CONCLUSIONS

The aim of this study was to find out, whether the soil C status is affected by the farming system and the used farming practices in the Mid-Hill region of Nepal. Clearly, it is shown that the soil C stocks are significantly higher in upland compared with lowland. This finding is in accordance with the other studies conducted in the Mid-Hill region and similar sloping land agroecosystems. Different microclimates, as well as diverging farming practices, are supposed to be the main factors driving the soil C accumulation. This study investigated the effects of the farming practices in the upland and lowland system both together and separately, and was to my knowledge the first study set out that way in the region.

This thesis research indicates that vegetation cover, agroforestry, and weed management with weed residues left on the field, are associated with higher soil C stocks. The observed negative relationship between the chemical fertilizer use and soil C sequestration implies that there is a need for alternative fertilization in crop production. Although the effects of the use of compost, tilling method and intensity, crop residue management, irrigation and crop rotation on soil C are not among the key findings in this study, many other authors have found soil C enhancements through the use of organic fertilizers and conservation agriculture practices. Thus the results obtained within this thesis may be partly a matter of a small sample size. A further analysis including the effects of altitude, topography and microclimate can provide more accurate knowledge of the impact of farming practices in different farming systems and slope positions. Practical limitations typical for the two farming systems must also be addressed for finding the optimal C management practices under the conditions of upland and lowland.

This study suggests that the aboveground vegetation cover, whether in the form of crop cover, trees, or weed residues, is an integral part of the soil C sequestration in the sloping agricultural lands in the Mid-Hill region of Nepal. The reason for the suggestion lies in the result that the vegetation cover had a positive effect on soil C accumulation in every system measured, and this outcome runs parallel with several other studies. However, owing to the limited sample size, any generalization on a broader scale should be treated with caution. Further research and systematic soil analysis are needed in order to fully investigate the farming practices contributing to the greater soil C contents in the region.

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APPENDIX 1. SOIL PROPERTIES

Table 10. Soil properties in the upland plots.

Laboratory	Purbanchal University						University of Helsinki	
Sample ID	Soil type	pH	Potassium (kg/ha)	Phosphorus (kg/ha)	Organic matter (%)	Total nitrogen (%)	Total nitrogen (%)	Total carbon (%)
1UP	Sandy clay loam	5.35	224.00	61.69	4.02	0.20	0.15	1.62
2UP	Clay loam	5.2	156.80	30.69	6.03	0.30	0.19	1.89
3UP	Clay loam	5.29	537.60	35.32	3.02	0.15	0.19	1.92
4UP	Clay loam	5.40	448.00	31.04	3.02	0.15	0.17	1.71
5UP	Silty loam	5.37	179.20	68.11	3.02	0.15	0.10	0.67
6UP	Sandy clay loam	6.04	246.40	68.82	4.36	0.22	0.28	3.08
7UP	Silty clay	7.07	336.00	54.21	6.03	0.30	0.18	1.96
8UP	Clay loam	6.00	492.80	63.83	1.34	0.07	0.16	1.57
9UP	Clay	5.45	649.60	74.88	4.02	0.20	0.15	1.45
10UP	Silty clay loam	5.60	560.00	71.32	3.02	0.15	0.19	1.88
11UP	Silty clay loam	7.20	627.20	73.10	4.36	0.22	0.14	1.36
12UP	Silty loam	5.50	201.60	68.11	4.36	0.22	0.16	1.54
13UP	Silty loam	5.90	470.40	65.97	4.69	0.23	0.18	1.69
14UP	Clay loam	5.90	134.40	60.27	4.36	0.22	0.21	2.12
15UP	Silty loam	5.20	201.60	67.40	3.35	0.17	0.14	1.23
16UP	Silty clay loam	5.40	67.20	69.54	3.02	0.15	0.16	1.42
23UP	Silty loam	6.46	112.00	39.95	3.69	0.18	0.14	1.28
24UP	Silty clay loam	6.80	761.60	49.93	5.03	0.25	0.21	1.92
26UP	Silty loam	7.10	1792.00	65.61	4.36	0.22	0.17	1.69
27UP	Silty loam	5.90	380.80	69.98	5.36	0.27	0.15	1.35
28bUP	Silty clay	5.20	761.60	73.10	4.36	0.22	0.26	2.63
29UP	Silty loam	6.20	963.20	65.97	3.69	0.18	0.22	2.13
30UP	Silty loam	6.10	1881.60	47.08	4.36	0.22	0.20	1.94
31UP	Clay loam	5.60	358.40	36.75	4.02	0.20	0.19	1.81
32UP	Silty clay	5.40	470.40	24.98	4.36	0.22	0.22	2.10
33UP	Sandy clay	5.50	761.60	32.11	4.36	0.22	0.22	2.21
34UP	Silty clay loam	7.40	1097.60	41.02	4.36	0.22	0.23	2.41
50UP	Silty clay loam	4.80	268.80	57.42	5.03	0.25	0.21	1.86

Table 11. Soil properties in the lowland plots

Laboratory	Purbanchal University						University of Helsinki	
Sample ID	Soil type	pH	Potassium (kg/ha)	Phosphorus (kg/ha)	Organic matter (%)	Total nitrogen (%)	Total nitrogen (%)	Total carbon (%)
17LW	Silty loam	6.80	179.20	38.53	4.02	0.20	0.15	1.37
18LW	Sandy clay loam	6.80	179.20	67.40	3.69	0.18	0.11	0.95
19LW	Silty clay loam	7.20	224.00	61.34	3.35	0.17	0.10	0.80
20LW	Silty loam	5.80	112.00	63.83	4.02	0.20	0.13	1.04
21LW	Clay loam	6.40	425.60	63.12	4.36	0.22	0.16	1.32
22LW	Silty loam	6.70	112.00	38.88	5.03	0.25	0.09	0.84
25LW	Silty loam	6.60	425.60	67.75	3.69	0.18	0.11	1.02
35LW	Silty loam	5.90	268.80	60.98	4.36	0.22	0.10	0.83
36LW	Clay loam	6.06	246.40	56.70	5.36	0.27	0.14	1.15
37LW	Silty clay loam	6.30	761.60	59.91	4.69	0.23	0.09	0.54
38LW	Sandy clay loam	6.80	425.60	75.59	4.02	0.20	0.14	1.11
39LW	Sandy	5.90	806.40	70.96	3.35	0.17	0.24	2.26
40LW	Sandy clay	5.90	537.60	73.46	4.02	0.20	0.19	1.63
41LW	Sandy clay loam	6.00	201.60	34.25	4.02	0.20	0.14	1.28
42LW	Silty loam	6.40	694.40	43.52	4.02	0.20	0.14	1.15
43LW	Silty clay loam	5.56	336.00	55.28	4.69	0.23	0.24	2.20
44LW	Silty loam	6.80	156.80	49.58	4.36	0.22	0.11	0.97
45LW	Clay loam	6.00	67.20	25.70	4.36	0.22	0.09	0.72
46LW	Silty clay loam	6.00	560.00	57.77	4.69	0.23	0.19	1.67
47LW	Sandy loam	6.80	201.60	39.95	4.02	0.20	0.16	1.38
48LW	Loamy sand	5.50	112.00	49.22	2.68	0.13	0.09	0.62
49LW	Clay loam	5.80	224.00	49.22	4.02	0.20	0.13	1.04